Enabling India's Bold Telecommunications Initiatives: A Technologist's Perspective

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Executive Summary

India's bold initiative to dramatically modernize its telecommunications infrastructure will allow the nation and its citizens to more fully participate in the global "e-conomy" and to enjoy its myriad benefits. Though the task seems daunting, India is well positioned, thanks to her expanding fiber optic and wireless networks, increased deregulation/competition, and her burgeoning high-tech sector, including a large and growing cadre of highly educated engineers and computing/software professionals. Equally important, India's initiative is timed to take advantage of the giant strides in communications technologies, especially opto-electronic, wireless and packet networking technologies, that can provide tremendous cost savings and operating benefits

India has a powerful opportunity to leapfrog other nations by swiftly creating a world-class telecommunications infrastructure leveraging existing assets and new technology:

- **A high-capacity, multi-protocol, backbone network that can grow in stages, as traffic needs and coverage expand. Optical switching, wavelength division multiplexed transport and a mesh architecture will "future proof" this backbone network at lowest cost.**
- **Utilize existing infrastructure (e.g., Re-use existing fiber for metro and core networks. Use existing rights of way, e.g. railways.)**
- **Low-cost, high-speed, optical, metro access networks for multimedia communications in high-tech metropolitan industrial clusters.**
- **Domestic Web-hosting infrastructure for local, regional, and international markets.**
- **A Softswitch-based, open communications platform for fixed and mobile applications, with new services developed indigenously, and marketed worldwide.**
- **Provide lowest-cost high-speed Internet access, telephony, and digital video by exploiting the existing entertainment infrastructure and upgrading to two-way cable technology.**
- **High-speed access via "Communication Cafes" or other shared facilities to serve large numbers of users cost effectively - particularly in rural areas.**
- **"No frills", low-cost wireless access for basic telephony services in rural villages.**
- **As the hardware becomes a commodity, use indigenous software talent to develop low-cost appliances to serve local, regional, and international markets.**

A key enabler for creating these networks is a stable, yet evolving, network platform, based on a long-term technology roadmap. Just as the U.S. has benefited enormously from the evolving "Wintel" platform for computers, India can benefit from a stable, evolving network platform. *This will attract investment from Indian and foreign telecom industries.*

By acting now, India has an unprecedented opportunity to cost-effectively build—in a short time and in an evolutionary fashion—a next-generation, world-class network. *This network can certainly be at par with—indeed, has the potential to exceed—the power of similar networks being built in the "developed nations."*

Objectives

India has embarked upon a bold initiative to rapidly bring the telecommunications infrastructure of the world's second-most-populous nation into the Twenty-First Century. The goals are:

- Increase the teledensity to 15% in the next ten years, adding 150 million new lines — five times the lines deployed in the preceding 60 years.
- Provide reliable and effective basic telephone services to the 350,000 villages that do not have telephone service today.
- Quickly provide a modern, broadband, IP-based, communications infrastructure, seamlessly connected to the rest of the world, to support both demand for Internet access and the advanced needs of the burgeoning high-tech industry.

India's aggressive deregulation is helping to achieve the bold communications objectives of the government. Key highlights of new and proposed regulatory changes include:

- National Long Distance deregulated and opened to all.
- The Department of Telecommunication (DoT) has been converted to a Corporation (BSNL) to provide a level playing field.
- ISPs have been permitted to connect directly to the submarine cables and to set up their own satellite gateways
- BSNL licensed to provide cellular service all over the country as a third cellular operator
- Policy to allow a 4th cellular operator announced.
- Policy announced to allow Private Basic Operators to provide "WILL Limited Mobility" using CDMA infrastructure.
- BSNL has issued orders to cover villages by using CDMA WILL system.
- International Long Distance will be deregulated and opened to all by 2002. Private operators planning submarine cables.

Of particular importance, is the "WILL Limited Mobility" using CDMA infrastructure recommendations proposed by TRAI on January 8, 2001, since this will enable basic services operators in India to deploy telephony and data services rapidly and cost effectively, thus meeting the aggressive growth projections (15% teledensity by 2010) of the government. Highlights of the TRAI recommendations include:

- Basic Operators should be allowed to offer limited mobility through WILL. This service should be provided as part of the Basic Service license itself.
- No additional entry fee and license fee should be required to provide this service. The current entry and license fee for basic services, which the operators are already paying, should not be altered.
- Extent of mobility should be within the Short Distance Charging Area (SDCA).
- Tariffs for Limited Mobility will be the same as a local call
- No additional entry fees for the spectrum, other than what is already being paid by the operators, is recommended.

The fundamental approach for India to take to meet its bold initiatives and leapfrog to the forefront of the communications infrastructure is by effectively leveraging her existing assets (infrastructure and technology) and by exploiting rapidly improving telecommunications technologies.

Leverage India's vital assets

Daunting, as the task may seem, India is well started toward its initiative:

- India has more than 185,000+ route kilometers of fiber installed nationwide. Existing inter-city fiber-optic cable can be used to add new capabilities to the backbone network. Furthermore, since the new design extends the reach of fiber everywhere, fiber can be reused in the access portions of the network. In addition, India's railroad system, the most extensive in the world, is ubiquitous, providing convenient rights of way for new optical cable installation.
- The Department of Telecommunications network already provides narrowband services to over 32 million subscribers connected by copper wire in the local loop. Using new technology such as xDSL, this network can be leveraged to provide broadband services without changing existing switches or copper.
- India's wireless communications industry is thriving: infrastructure is in place and growing rapidly; competition is vigorous, and the subscriber base is more than doubling each year with over 2.6 million wireless subscribers today. New revenue-generating services, developed in India, can be offered to these subscribers by converting existing GSM networks to 3G/GPRS broadband systems.
- India has more television sets than telephones—and some 30 million Indians have cable TV connections, expected to grow to an estimated 80 million by 2008. Fast deployment and new revenue generating services can be offered by upgrading the growing cable access infrastructure to carry two-way broadband communications to homes and offices.

India has an expanding high-tech sector, led by highly trained engineers and computing/software professionals. India trains about 68,000 professionals a year. Today about 280,000 Indians work in the software and services sector, constituting the world's second largest information technology workforce. Total exports of software last year amounted to about $4 billion, growing at a compound annual rate of about 61 percent over the last five years. Target is $50 billion in exports by 2008. India's domestic software market value is about $1.8 billion, with a 41 percent compound annual growth rate. *Thus, India's information technology workers are a global force, prepared to contribute to the development of state-of-the-art telecommunications and information services, and worldwide connectivity.* Furthermore, the communications infrastructure already being deployed to support their needs provides a base to accelerate the creation of a multiservice nationwide network that can meet the needs of the other users.

Leverage Technology Advances

Equally important, India is poised to take advantage of the spectacular advances in optical, microelectronics, wireless and software technologies to achieve her demanding deployment and cost requirements. Unlike many "developed nations," India is not constrained by embedded infrastructures that may be decades old. Instead, she can cost-effectively exploit the worldwide movement toward building open, global service platforms to facilitate the development and rapid deployment of optical networks and IP-based services. The ever-improving cost/performance benefits of telecommunications technologies are the key to building the low-cost network components that India needs to achieve her objectives.

Fundamental technological advances in several key areas underlie India's telecommunications initiative:

- *Optical — Optical communications technologies are improving by a factor of more than 100 every decade, and the cost of transporting a bit over an optical network, declining by half every nine months*

and with no end in sight, is already at the point where basic voice service can be carried virtually "free." To put these advances in perspective: The first commercial fiber-optic systems, introduced only 20 years ago, provided 45 megabits per second, equivalent to 672 phone calls, per fiber, with repeater spacing of 7 kilometers. Today's commercial systems, using dense wavelength division multiplexing techniques, deliver 400 gigabits per second (equivalent to more than 5 million telephone calls) on a single fiber, with repeater spacing of 640 kilometers.

- *Microelectronics — "Moore's Law," which holds that the number of transistors per silicon chip doubles every 18 to 24 months, continues to drive down the cost and improve the functionality of every type of electronic circuit.* The "Law" is expected to be "enforced" by several exciting new technologies being actively explored, such as ultra-dense, three-dimensional integrated circuits formed by stacking layers of transistors one on top of the other, and "vertical" transistors, which are 2,000 times thinner than a human hair.
- *Switching/Routing — The advances in optics and microelectronics (especially the use of application-specific integrated circuits -ASICs) are enabling new terabit-capacity, protocol-agnostic, switches and routers and simpler, lower-cost network architectures.* These systems and architectures will permit switched virtual circuits (SVCs) to be established at rates exceeding 1000 per second. New optical switching elements with embedded signalling and distributed control will transform optical networks from high-bandwidth facilities to routed services facilities interworking with the switched voice network, ATM SVC networks and IP-packet routed networks. These architectures combined with software advances described below, will transform the network into an open service platform with quality of service, security and safety from harm.
- *Wireless — Over the past ten years, the use of mobile communications has become so pervasive that subscriber penetration rates have reached more than 50 percent in many markets around the world, and mobile phone outnumber wired phones in many nations—achieving, in a decade, a century's worth of work for the world's wired telephony systems.* Broadband, fixed-wireless systems are being deployed where wired solutions are too costly or not feasible to install. Development of new, spectrum-efficient antenna technologies and high speed digital wireless systems enable scarce radio spectrum to carry far more communications traffic at very high quality for voice, Internet access and video services.
- *Software — Scientists and engineers have pioneered distributed and scalable software that is allowing open platforms for global communications services to be created, provisioned and billed far faster, in response to ever-accelerating demands for more individualized voice, data and multimedia capabilities.* Instead of being tied to a single vendor's products, new network systems feature programmable service-creation platforms for new and customizable network-based services by third-party vendors using open applications programming interfaces. The Internet itself is providing a strong push for software advances through its ceaseless implementation of packet networking technology, as well as the globally pervasive use of HTML and Java programming, and browser software.

Solution for India

India has a wonderful opportunity to create a 21st century communications network – surpassing the networks of other countries, even developed nations. This can be accomplished by:

- Creating a high- capacity, low- cost, future-proof, optical meshed backbone network that meets all of the service needs of today and tomorrow with high quality.
- Creating cost- effective, rapidly- deployable access solutions to meet its diversity of needs

ranging from high tech metro to basic rural services.
- Accelerating information, services, and applications economies while providing services to all its communities.

The proposed solution for India is based on using new emerging technologies and leveraging existing assets to provide a future-proof, lowest-cost network infrastructure. These will be described below.

India's Leading-Edge Backbone Network

The foundation of India's next-generation communications system is a high-capacity backbone network, powerfully positioned to fully exploit new technology. By taking advantage of the spectacular progress in optical technologies, including optical routing, DWDM transport, mesh architectures, and elimination of packet-level processing, India will be able to create a high-capacity, low-cost, "future-proof" network. Thus, India will be capable of accommodating anticipated and even unanticipated growth with scaleable network elements that can expand to meet dynamic demographic and economic conditions—even when such changes cannot be predicted accurately. Moreover, the forward-looking design will be in harmony with India's expectations of greater demand stimulated by the substantial economic growth enabled through a first-tier communications infrastructure.

With the market price of fiber at approximately $50 per fiber kilometer, and installation at a rate of about 5,000 fiber kilometers per hour worldwide, the cost of bandwidth is no longer a factor in new network deployment. The capacity of each strand of fiber is doubling every year, and terabit-per-second speeds are a certainty on the near horizon. (N.B.: Researchers last year demonstrated 320 Gb/s on a single wavelength, and also transmitted more than a thousand wavelength channels of light on a single fiber using a single laser source.) *India can improve her telecommunications business models to emphasize services, not bandwidth, as the key factor in charging customers for value delivered.*

Backbone Inter-City Network Architecture

India's backbone network must have a basic fabric that supports multiple services in multiple formats—not only time division multiplex, but also packet and cell-based services. *The future network design will offer integrated voice and data services from a single, integrated transmission network, terminating and switching those traffic types in their native modes at the first point of switching on a single platform.* A single integrated network will offer lower life cycle cost, a richer market basket of services and more efficient network management and operations. In addition, the backbone network can potentially interconnect seamlessly with existing regional and national long distance networks of basic, wireless, and cable operators to cost-effectively accelerate the creation of a nationwide network.

Given the anticipated growth rate and diverse, unpredictable services, India will need a multi-services (IP, ATM, FR, TDM) optical mesh backbone connecting Tier 1 cities, international gateway switches and data centers for high capacity, high throughput traffic (Figure 1). The traffic in the backbone will switch individual wavelengths, delivering virtually limitless capacity while supporting any protocol or bit rate over shared facilities. By modularly adding wavelengths as needed, the network can be extended to grow the geographical coverage in stages. This backbone network will handle high-bit-rate traffic between inter-city nodes. The network will be able to support new broadband services such as dial-up wavelengths. India will benefit from another powerful technological trend — integration of electronic and photonic components on a single chip. This approach eliminates the current need to convert signals from optical to electronic for processing. All-optical

processing can save service providers up to 25 percent in operational costs and enable them to direct network traffic 16 times faster than with electrical switches, with up to 100 times less power consumption.

A leading-edge technology for wavelength switching is micro-electromechanical systems (MEMS), which use microscopic mirrors formed on a silicon substrate, tilting to switch individual wavelengths of light without first converting them to electrical form. These "lambda routers" will be deployed at each inter-city node to carry traffic on the backbone network. This approach permits fast rearrangement of wavelengths to dynamically adjust to demand, increase performance and achieve high reliability in the backbone network.

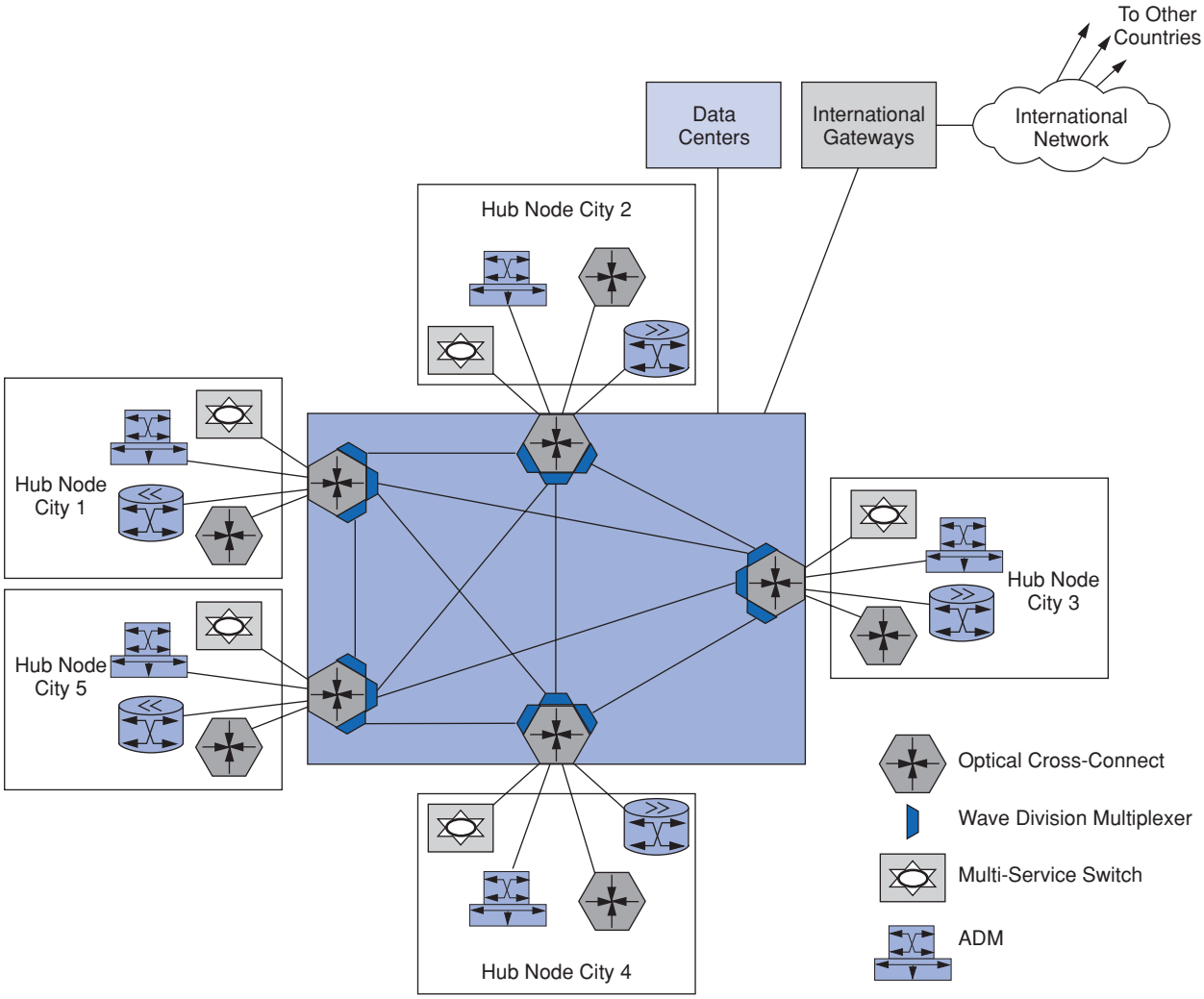

Figure 1 –Backbone Inter-City Backbone Network

The backbone network also will include sophisticated network management capabilities to provide responsive, economical operations, administration and maintenance support, rapid provisioning of new services and billing arrangements. The network will self-heal automatically around failed links, providing near-instantaneous recovery. Furthermore, the backbone network will economically and rapidly support and deliver basic and advanced voice and data services, with bandwidth on demand. It will accommodate all protocols (Asynchronous Transfer Mode, Internet Protocol, Frame Relay, Time Division Multiplex), making the backbone totally "future-proof." In particular, as the services migrate from TDM voice, IP data, IP over ATM, to future integrated protocols (e.g., VoIP, MPLS, MPλS), the backbone will be ready without any overhead. It is anticipated that most traffic will be Internet Protocol-based. (N.B.: India's Internet services sector recorded 297% growth over 1999. The Internet subscriber base crossed the 1 million mark in 2000.) Moreover, it is expected that voice traffic will transition to IP with performance characteristics approaching today's circuit-switched digital networks.

Access Architectures for India

With access typically accounting for 50-70% of overall network costs, the biggest challenge in communications networking systems is to provide cost-effective access solutions. Appropriate access technology options need to be adapted and refined to meet India's unique needs. Willingness of users to pay for the services will drive technology deployment to a large extent.

Metro/regional network architecture

The metro area's architecture must accommodate business customers with demanding service needs as well as end users who are satisfied with basic service. Moreover, the economics of various access technologies vary significantly across different types of regions, topologies, population densities, and service mixes. *Capable, economical, "future proof" access is crucial to the viability of India's initiative.*

A high level view of the Metro/Regional Network is given in Figure 2. One or more Hub Nodes (HNs) can serve the Metro or Regional area's communications needs. The HNs concentrate, route and switch all traffic within the Metro or Regional area. Traffic from the access network is concentrated at individual access nodes and carried over protected metro or regional DWDM fiber rings.

Innovations in new access technologies are continually driving new capabilities to lower cost points. The principal technologies for access options are:

1. *Fiber Access — The continued drop in the cost of providing optical links in backbone networks is pushing higher bandwidths directly to customers, meeting unprecedented demands based on increased Internet usage and new applications, such as video on demand.* Advances in metropolitan optical networking now support multi-megabit and even gigabit Ethernet on fiber to offices. Low-cost, passive optical technologies hold the promise of fiber to the home. *The result is that business and residence users can have access to high bandwidth services:*
   - *Fiber to the business for gigabit services* for business customers requiring high bandwidth with stringent reliability and performance requirements for applications such as video on demand and high-speed Internet access.
   - *Passive Optical Networks (PON)* for high-end residential customers. Although this technology is expensive now, technological innovations and customer demands for high capacity throughputs will bring costs down to affordable levels.
2. *Wireless Access — Much research and development activity is focused on meeting explosive demand for rapid, ubiquitous service deployment with limited spectrum availability.* Advances in wireless technol-

ogy are expected to significantly reduce wireless appliance costs and speed the deployment process for new subscribers. Wireless technology advances that can benefit India by increasing capabilities and reducing costs include:

- *3G systems* will provide high-speed data and multimedia via high-bandwidth mobile wireless systems at low cost. Packets in the air and packet routing will bring Internet/web access to mobile users. Digital signal processing and ASICs will subsume more and more of the radio functions into *software radios* thus providing a platform for multiple standards and services, with new functionality provided via software downloads. India's IT prowess can improve further by providing mobile computing. Indigenously developed mobile e-commerce applications - from banking to entertainment - can help reduce the costs of additional infrastructure.
- *BLAST (Bell Labs Layered Space-Time) Technology* has the potential to boost the capacity of future fixed wireless loop systems. BLAST technology exploits the capability to extract several distinct transmissions occupying the same frequency band. Each transmission uses its own transmitting

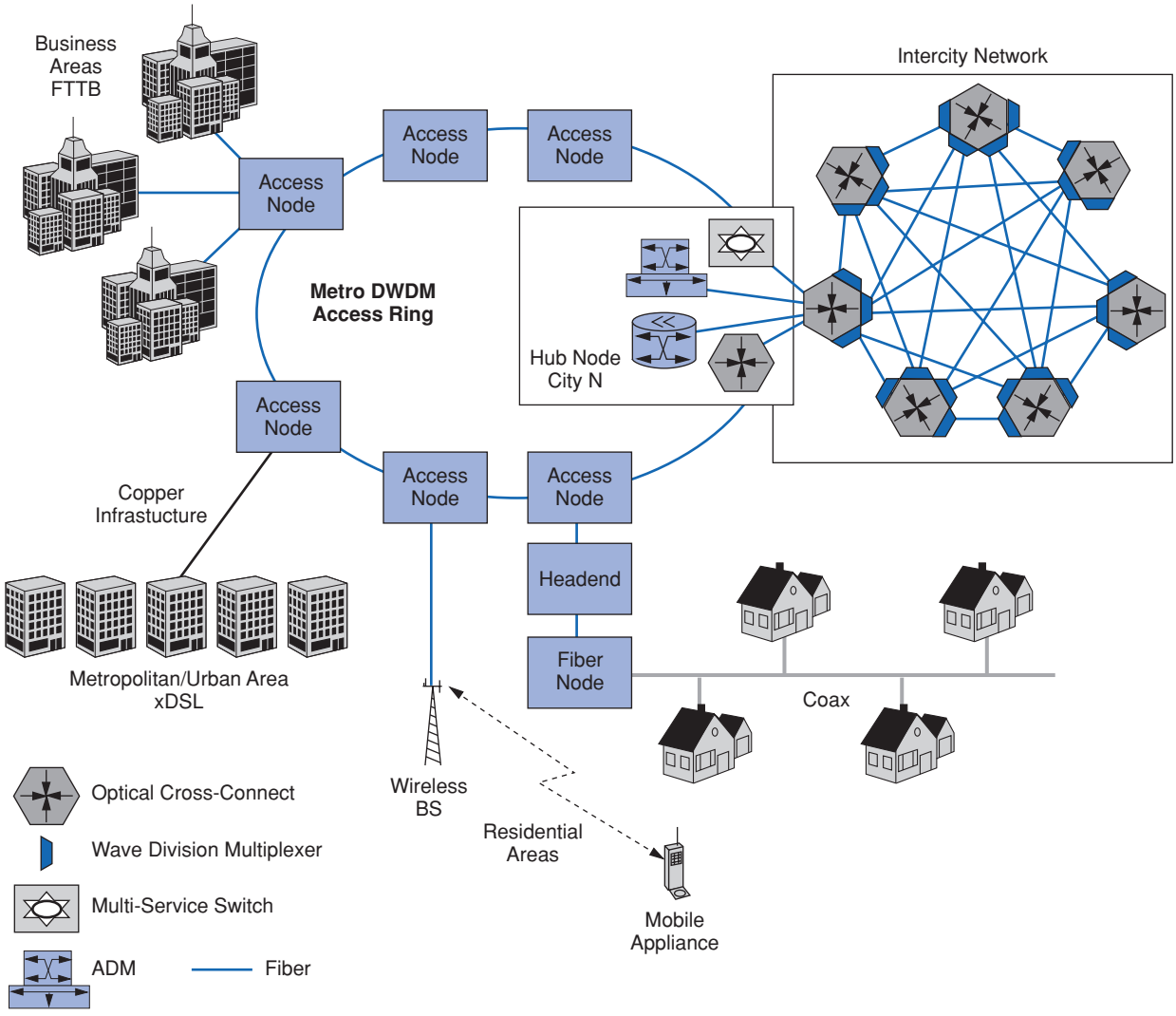

Figure 2 – Metro/Regional Network Architecture

antenna, while multiple antennas are used at the receiving end, along with innovative signal processing, to separate the mutually interfering transmissions. Thus, the capacity of a given frequency band could increase proportionally to the number of antennas. Feasibility has been demonstrated with a prototype system.

- *Bluetooth technology* is expected to revolutionize personal communications by allowing cellular phones, PCs, personal digital assistants (PDAs) and other devices to share information reliably without the need for wires. A wireless connection is made via a short-range radio that uses the 2.45 gigahertz ISM band available worldwide.
- *Steerable "smart" antennas* can concentrate a radio beam of considerably lower power aimed automatically and directly at a mobile, providing greatly improved communications, reduced interference, and increased spectral efficiency resulting in significantly greater system capacity. Smart antennas could allow more subscribers to be served per megahertz of spectrum per square mile.
- *Small Base Stations* take advantage of pico cellular and micro-cellular technology, allowing them to be installed almost anywhere since their size is equivalent to a PC. System capacity can be increased, since frequencies are reused more often without interference.

Wireless technologies that can be exploited now include:

- *High-speed wireless Internet and multimedia services* (also known as Local Multipoint Distribution Systems) for business customers in areas where wired infrastructure currently does not exist or cannot reach economically.
- *Multi-point Microwave Distribution System* (also called wireless cable) to serve the needs of residential customers for voice, video, and Internet access.
- *Wireless local loop (WILL)* for areas where no infrastructure exists to provide very low cost residential services, including voice, low/medium speed data, Public Telephone, and fax. Existing fixed GSM and CDMA technologies can be used to serve this need.

3. *Cable Access — Given the large cable deployment in India, re-using the cable infrastructure to provide voice and Internet service is a potentially attractive access option for millions of users.* User demand for high-speed Internet, video and other large-capacity services will drive deployment of broadband two-way cable, along with next generation cable modems. Complex technical issues relating to upgrading one-way cable systems to two-way must be addressed, given that 90% of the cable deployed in the network is one-way. Innovative technologies will need to be developed in India, by leveraging experiences of cable operators elsewhere in the world.

   The impetus for the growth of cable is not the voice but the tremendous attraction of Indians to seeing movies on TV. Thus, deployment of cable infrastructure will continue to keep growing. The new cable networks being put in place today use two-way cable and are designed much better. Almost all cable TV companies have started conversion of one-way cable networks to two-way cable networks. Furthermore, the convergence bill passed by the Indian parliament already professes one medium for all services. Thus, as soon as VoIP becomes legal in India, voice will also be permitted to the cable operators. This is the cable operators' big attraction. Today, Internet is already being offered over cable in cities such as Delhi. Some of the new basic services operators are also planning to build their own two-way cable networks. With a two-way cable infrastructure in place, the following capabilities can be offered:

   - *Voice and data over cable* for residential customers providing high speed Internet access, video, and voice over IP (VoIP). Subscribers in those areas could use either a PC with appropriate cable modems, or low-cost Web TV-type appliances hooked up to TV sets. By 2008, it is estimated that India will have 35 million cable Internet subscribers; up from today's one million.

4. *Copper Access* — High-speed access for business users could be provided by reusing and upgrading embedded copper through xDSL technology. New copper infrastructure may also be deployed economically in high-density areas to serve residential customers. Services provided could include voice, high-speed data, and video.

The demand for high-speed Internet access is growing rapidly, worldwide. Figure 3 shows broadband access technology options and their potential time of deployment.

Rural network access architecture

The approximately 607,000 rural villages in India are classified into two types as shown in Figure 4:

- Clustered — where several villages are located near large cities or towns
- Isolated — where a village is isolated from other villages and towns.

The clustered villages can be served by limited mobility CDMA wireless systems (or WILL), from the fiber rings that traverse the metro/regional networks. Given the close clustering of villages (typically 5-10 Km distances), many villages can be effectively served by strategically located base stations that could cover distances up to 50 kilometers, even in low-density areas. It may be appropriate to set up "Communication Cafés" or, as the Honorable Minister of Communications Shri Ram Vilas Paswan, calls them "Sanchar Dhabas" in these clustered villages that offer Internet access, video, and telephony services for the community. These Community Communication Centers will provide integrated communication facilities in all of the rural areas and small towns. By leveraging the infrastructure and access node costs between urban and rural areas, the cost to provide this service in the clustered villages can be relatively low. CDMA WILL, the chosen technology for high data rate 3G wireless systems, is an appropriate technology to bridge the digital divide between the urban and rural areas.

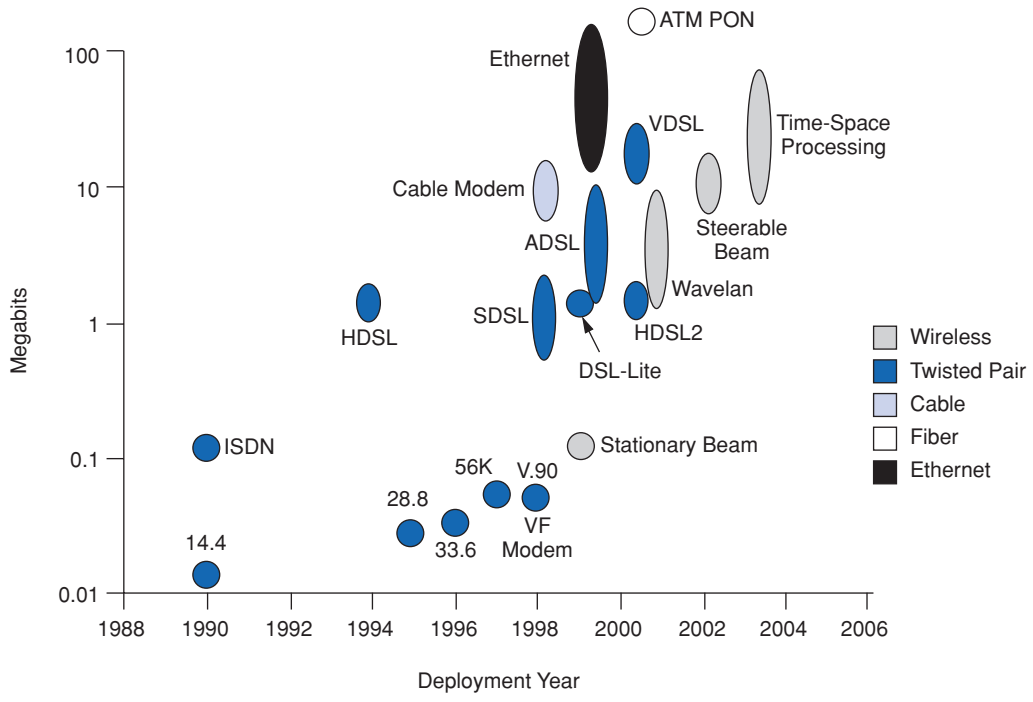

Figure 3 – Access Technologies

VSAT is the preferred technology option for isolated villages. VSAT has been successfully deployed in many countries around the world. Given the relatively high cost of VSAT terminals, sharing the overall access infrastructure cost with VSAT can lower overall per-line deployment cost. Operators can provide prepaid card options for rural subscribers to address billing and collections needs.

Applications capabilities

Today, most Web portals are located outside India — even those portals developed in India to serve local user needs — primarily because India has relatively few Internet subscribers and ISPs, as well

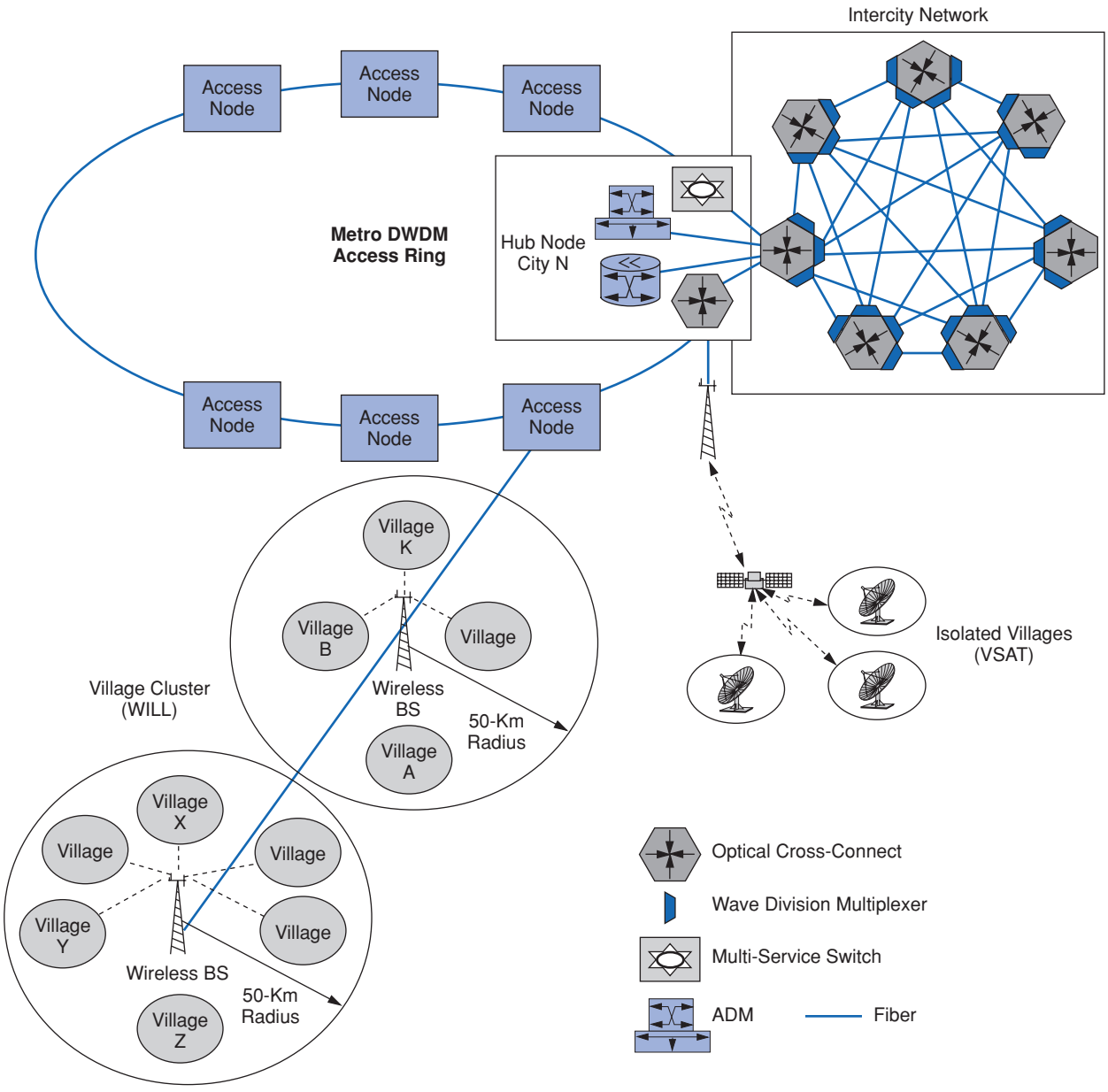

Figure 4 – Rural Network Architecture

as limited existing IP infrastructure. Furthermore, access to ISPs is expensive and slow because of the need for international connectivity and limited IDD bandwidth available. *Projected high demands from new subscribers will make it economically feasible for new ISPs to host their Web portals locally (data centers) on the core backbone network, thus decreasing the high IDD tariffs and traffic bottlenecks. Lower costs, coupled with higher throughput capability, will stimulate additional customers to use the services, resulting in additional revenues for ISPs and service providers. Furthermore, local hosting of Web portals by ISPs can generate additional revenues from international access.*

India's excellent and extensive software development resources offer tremendous potential to develop new Web-based e-commerce applications and portals for Data Center applications. The relentless communications cost reductions driven by "Moore's Law," and wireless and optical technologies, combined with Softswitch-based open communications platforms enable new, revenue-producing services at low costs. An open services creation environment, through Applications Programming Interfaces, will permit full participation by third-party vendors to customize or regionalize network applications in local languages, and create new services nimbly and economically. *This capability will enable India to leverage her increasingly powerful software capabilities to develop new applications. Those, combined with applications developed elsewhere, can be hosted from India, to help advance the Government's telecommunications objectives. These applications can generate profitable revenues and help support "free" transport of basic voice communications.*

Appliances

A wide variety of appliances are required to cost-effectively support India's diverse customer needs. These appliances include:

- Low function, low cost, multi-use appliances (e.g., Web-TV). These appliances are easy to use and require low maintenance and support at an affordable price, helped in part by the network supplying most of the intelligence.
- IP Phones, PCs, IP-PBXs, etc., for customers with more advanced service needs who are willing and able to pay for such capabilities. The needs of these subscribers are best met by more intelligence in the appliances supported by intelligent network capabilities.
- Mobile appliances, such as cell phone, pagers, PDA's, wireless PCs, Global Positioning System interfaces, for the growing number of mobile subscribers.

Opportunities for India

The proposed network infrastructure provides many opportunities for India to leverage the talents of its technical assets, both human and institutional. A few specific technical innovative research and development activities related to India's needs are:

1. R&D in emerging wireless technologies (BLAST, Bluetooth, Smart Antennas, small base stations, etc.) to provide low cost access solutions in India and worldwide.
2. Software development for mobile Internet e-transaction applications that allow service providers to recover high spectrum license fees for these new services. In turn, the government can charge higher license fees, consistent with other countries, and use this additional revenue for social good.
3. R&D in low cost appliances and technology to develop voice, data, and Internet access over power transmission cables. This will be especially useful for villages, and community schools and hospitals.
4. Low cost appliances and technology to develop two-way voice, data, video and Internet access over Multi-point Multi-channel Distribution Systems (MMDS). This too will be especially useful for villages, and community schools and hospitals.

5. Low cost appliances (VSAT) and technology to develop voice, data, and Internet access over satellite to serve rural villages as well as compete with the above technologies in urban areas.
6. Software development of new applications and services. This effort can be extended to include activities relating to open standards, element and system level inter-operability, network management, testing, etc.
7. Focus research and development activities in research institutions targeted at the above and other new activities

These opportunities can be exploited with support from the government, industry and technical institutions and collaboration with leading R&D organizations around the world. Lucent Technologies' Bell Laboratories will be keen to collaborate in these endeavors, which have the potential to improve hundreds of millions of lives.

Conclusion

India stands on the brink of an exciting opportunity to bring an increasing number of its citizens all of the benefits of the Information Age with speed and overall economy that would have been unthinkable a generation ago. She can exploit the vast and accelerating improvements in optical, opto-electronic, wireless and software technologies to create a first-tier backbone telecommunications infrastructure that supports all current and envisioned needs, with voice services riding essentially "free" on top of sophisticated broadband data, multimedia and Internet services and transport.

Highlights of these capabilities include:

- **A high-capacity, multi-protocol, backbone network that can grow in stages, as traffic needs and coverage expand. Optical switching, wavelength division multiplexed transport and a mesh architecture will "future proof" this backbone network at lowest cost.**
- **Utilize existing infrastructure (e.g., Re-use existing fiber for metro and backbone networks. Use existing rights of way, e.g. railways.)**
- **Low-cost, high-speed, optical, metro access networks for multimedia communications in high-tech metropolitan industrial clusters.**
- **Domestic Web-hosting infrastructure for local, regional, and international markets.**
- **A Softswitch-based, open communications platform for fixed and mobile applications, with new services developed indigenously, and marketed worldwide.**
- **Provide lowest-cost high-speed Internet access, telephony, and digital video by exploiting the existing entertainment infrastructure and upgrading to two-way cable technology.**
- **High-speed access via "Communication Cafes", WILL or other shared facilities to serve large numbers of users cost effectively - particularly in rural areas.**
- **"No frills", low-cost wireless access for basic telephony services in rural villages using WILL.**
- **As the hardware becomes a commodity, use indigenous software talent to develop low-cost appliances to serve local, regional, and international markets.**

Broad architectural/technology choices should be decided soon so that government and/or private industry can direct investment to develop the appropriate infrastructure and avoid wasteful duplication.

Providing capable and appropriate access to all of her one billion citizens in major metropolitan areas and all of her more than 600,000 villages will be a challenge that India's planners will need to address even as they build the state-of-the-art backbone network. By taking advantage of leading-edge network technologies and trends, including open services architectures, India will be able to leverage her strong and growing cadre of engineers and software developers to help the nation and its citizens to be full participants in the global economy.

ABOUT THE AUTHOR

ARUN N. NETRAVALI, President, Bell Laboratories, Chief Technology Officer and Cheif Network Architect, holds a B.Tech degree from the Indian Institute of Technology in Mumbai and M.S. and Ph.D. degrees from Rice University in Houston, Texas, all in electrical engineering. A fellow of the IEEE and the American Academy of Arts and Sciences, as well as a member of the U.S. Academy of Engineering, he is also the recipient of an honorary degree from the École Polytechnique Fédérale in Lausanne, Switzerland. Dr. Netravali, who has authored more than 150 technical papers and co-authored three books, currently edits several journals. He also holds more than 70 patents in the areas of computer networks, human interfaces to machines, picture processing, and digital TV. In addition, he has received numerous awards, including the Alexander Graham Bell Medal, the OCA National Corporate Achievement Award, the Engineer of the Year Award from the Association of Engineers in India, the Thomas A. Edison Patent Award, the C&C Prize, and the Frederik Philips Award.